The shipping sectors’ CO2 emissions may play a larger role in the future, as the transport sector needs to reduce its carbon footprint in order to meet the climate goal of 2 degrees Celsius \cite{PARIS agreement paper …}. The shipping sector is still almost fully dependent on fossil fuels for its energy means, and need to shift to a sustainable energy. CO$\_2$ emissions from shipping in 2012 amounted to a total of 949 million tonnes, contributing to 2.7\% of global anthropogenic CO$\_2$ emissions \cite{Smith2014}. Although this contribution appears relatively low, the trend is that shipping will play an even greater role in the future due to the increased transport demand according to all IMO future scenarios \cite{Smith2014}. In the transition to a sustainable shipping sector all means need to be counted for, and better knowledge of the individual energy and exergy flows can be used to further optimise the existing designs. Making the shift towards sustainability faster.

Study on global shipping emissions. \cite{Global assessment of shipping emissions in 2015 on a high spatial and temporal resolution, Lasse Johansson et al.}

About regulations on shipping emissions… \cite{Regulating GHG Emissions from shipping: Local, global, or polycentric approach? Gritsenko}

As an example, global transport demand has increased by 3.4\% in 2014, compared to a global GBP growth of 2.5\% the same year, which shows how shipping tends to rise even faster than global economy \cite{UNCTAD2015}. The OECD countries have reduced the CO$\_2$ impact from shipping, but a larger amount has been moved to the non-OECD countries [3]. The fact that shipping needs to even further reduce its CO$\_2$ emissions in the near future is essential for being able to achieve the goals of maintaining the climate below a 2-degree level in 2050 [4].

In addition to considerations related to GHG emissions, an emission control area (ECA) is enforced in the Baltic Sea by the International Maritime Organisation since January 2015. This ECA stipulates that the fuel used must not contain more than 0.1\% sulphur, therefore requiring the use of more expensive distillate fuels. More generally making shipping sustainable is a challenge that will demand growing attention by the shipping industry \cite{Andersson2016}

Altogether, these conditions present a challenge to the shipping companies who attempt to reduce their fuel consumption, environmental impact, and operative costs. A wide range of fuel saving solutions for shipping are available and partially implemented in the existing fleet, both from the design and operational perspective; several specific studies have been conducted on these technologies, and a more detailed treatise would be out of the scope of this work. In this context, it has been acknowledged that the world fleet is heterogeneous, and measures need to be evaluated on a ship-to-ship basis \cite{Bouman2017}. In this process, a deeper understanding of energy use on board of the specific ship is vital.

\subsection{Previous work}

The idea of improving the understanding of the behavior of the energy system of a ship is not new. Most of the work published around this subject relates to the use of mathematical models of the ship systems.

Most authors focused on the propulsion part of the problem, as this is often the most relevant energy demand on board. Shi et al. proposed a modeling approach for predicting ship fuel consumption of a cargo/passenger ferry \cite{Shi2009}; Theotokoats and Tzelepis applied a similar procedure to the case of a Handymax product carrier \cite{Theotokatos2015}, similarly to Tillig et al., who also added the dynamic element to their predictive model \cite{Tillig2016}.

The work referenced above allowed improving the understanding of how many operational (such as the ship's speed) and environmental (such as wave height and wind speed) parameters influence the ship's energy performance. These studies, however, are not based on actual measurements of the ship's operations. Also, they focus entirely on the ship's power demand for propulsion. This is a very reasonable practice for most ship types, given that propulsion represent the largest part of the total energy demand, but does not allow improving the knowledge of the remaining part of the system.

% Data-driven analysis

Other authors filled the gap by both including electric energy demand, and by basing their work on measurements from actual ship operations. The work presented by Thomas et al. \cite{Thomas2010} and Basurko et al. \cite{Basurko2013} shows the application of energy auditing methods to fishing vessels. This approach represents a step forward towards improving the understanding of how energy is used on board during actual ship operations.

More generally, several authors have highlighted the importance of a detailed knowledge of the ship's operational profile in order to appropriately assess and optimize possible alternatives for improving ship energy efficiency \cite{Banks2013}. Coraddu et al., started from a statistical analysis of measured ship operations and used the aggregated data, together with a computational model of the vessel, to provide a better prediction of the actual ship's operational efficiency \cite{Coraddu2014}. The importance of considering the operational profile was also showed in the case of the optimization of engine-propeller interaction \cite{Baldi2015c}, in the process of retrofitting existing systems \cite{Baldi2015b,Choi2013}, and in ship design \cite{Ghassemi2017,Solem2015}.

% Heat availability

Heat demand is rarely a subject of concern on board ships, with some notable exceptions. This is due to a combination of generally low demand and high availability from the waste heat of the engines. In a previous publications by the authors, for instance, it is shown that in the case of a product tanker, although the heat demand was estimated to account for roughly 20\% of the total energy demand of the ship on a yearly basis, it only contributes to 4.1\% of the total fuel consumption (contribution of the auxiliary boilers), while the rest of the demand is fulfilled using waste heat \cite{Baldi2015a}.

%% WHR and heat availability

It should be noted that, however, much research effort has been devoted, especially in recent times, to the improvement of the efficiency of ship energy systems by recovering the waste heat available from the engines. With reference to different types of technologies, case studies, and designs,the several authors showed the existance of a quite significant potential for energy saving when WHR systems are employed, ranging from around 1\% for single-pressure steam cycles applied to two-stroke engines \cite{Theotokatos2012} to more complex systems based on ORCs (up to 10\%, \cite{Hountalas2012}) or including the cooling systems as a source of waste heat (over10\%, \cite{Dimopoulos2012}). The case of the installation of an ORC on board of the vessel investigated in this study (see Section \ref{sec:met:case}) was presented in \cite{Mondejar2015}, showing a similar potential.

The potential uses for waste heat on board are not limited to improving the efficiency of the power plant. Waste heat is commonly used for fulfilling on board heat demand for spatial heating and freshwater generation \cite{Molland2011,Baldi2015a,Mccarthy1990}; Balaji et al. proposed the use of waste heat for ballast-water systems \cite{Balaji2012}; Salmi et al. suggested its use for adsorption refrigeration systems \cite{Salmi2017}. A detailed review of potential uses for waste heat from marine engines is presented by Shu et al \cite{Shu2013}.

% Cruise ships

Some ship types constitute notable examples. On cruise ships the heat demand is significantly higher compared to standard cargo ships. Referring to winter conditions, Marty et al. estimated the instantaneous heat demand of a selected cruise ship to reach roughly 23 MW, compared to an estimated peak of 49 MW for propulsion and electric auxiliaries combined \cite{Marty2012}.

This shows how the heat from the engines should be considered as a potential resource, rather than a waste, and that there is potential for improvement based on the optimal use of these heat sources. The work presented by the authors in \cite{Baldi2016} represent a step in this direction; however, there is the need for an increased detail in the estimation of the heat demand.

% Exergy analysis

Exergy analysis provides a more accurate estimation of the potential for energy recovery on board. The application of exergy analysis to the case of ship energy systems is, however, still limited. Dimopoulos et al. showed how the process optimizing the WHR system of a container ship can be more efficient if exergy efficiency, rather than energy efficiency, is used as the target of the optimization \cite{Dimopoulos2012}; Baldi et al. also analyzed the exergy flows on board of a product tanker, showing that this allows having a more accurate understanding of what parts of the system show potential for improvement \cite{Baldi2015a}; similar results were obtained by Marty et al., who focused on the power plant of a cruise ship \cite{Marty2016}. Koroglu et al. made a step futher also including advanced exergy analysis in their study \cite{Koroglu2017}.